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ABSTRACT

The Common Knowledge: Pittsburgh (CK:P), a technology-based project, introduced the Internet into all levels of the Pittsburgh Public Schools during 1995-97. This is a case study of the ideology, strategies, and process of the CK:P project describes the project's activities, examines the project in light of school-reform literature, and uses its experience to develop a conceptual framework for discussing such reform efforts. The language of chaos theory is used to describe the behaviors observed in the project and argues that the behaviors exhibited, as a result of implementing the CK:P project, are nonlinear, dynamic, and similar at every entry--individual, school, and district--of magnification. Although the behaviors appear to be random, chaotic, and unpredictable, patterns or points of stable attraction exist within the randomness. The project experience suggests that at least four elements must be present for school reform to occur: (1) the individual or cultural change is irreversible; (2) the change is internalized by the majority; (3) institutional shifts occur to support and sustain the change; and (4) the change conforms to an agreed-upon standard. The value of applying chaos theory to school reform is that it is a holistic process for analyzing complex systems. Through mathematical modeling, chaos theory looks at systems globally while addressing local variables. It attempts to replicate a system's complexity by considering both the existing turbulence and that generated when introducing an agent of change. A glossary and four figures are included. (Contains 19 references.) (LMI)

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Attending to the Noise: Applying Chaos Theory to School Reform

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INTRODUCTION – School Reform

School reform is a hot topic in K12 education. It has been ever since mandatory public education was legislated in this country. Historically, school reform is often addressed from an ideological perspective (Kliebard, 1995; Ernest, 1991; Apple, 1983; Dewey, 1916). John Dewey began the reform discussion from the public educator viewpoint suggesting that schools should provide access and enlightenment for all citizens. The reform movement changed focus during the World Wars and Cold War taking on a social meliorist viewpoint, this time asking educators to meet the scientific and employment needs of society and country. Again in the 1960's, as a result of equal rights legislation, the focus changed to a progressive viewpoint that attempted to address and fulfill the promise of each individual. These ideological perspectives were reactions to the state of education and society at their specific moments in history. The constant in each of these school reform movements was dissatisfaction with the existing structure, its underlying ideology and the quality of student achievement it produced. The underlying belief of each movement was that the educational organization was not meeting some need, (often poorly defined).

Besides the ideological viewpoint, school reform efforts can also be categorized according to their strategic perspectives. One can view reform strategies in terms of scale – nation, state, district, school, department, teacher and student (Fullan, 1991). These strategies can be viewed from a market perspective – charters, vouchers, magnets and school choice (Chubb & Moe, 1990). One can view them from a systems perspective – organizational dynamics, Total Quality Management, shared decision making and site based management (Fiske, 1991). And, one can view these strategies from an educational perspective – curriculum reform, authentic assessment and professional development (NCTM, 1989, Clifford & Guthrie, 1988; Wiggins, 1989).

No matter what perspective, ideology or strategy, the goal of all school reform efforts has been and is to change some aspect of the organization believing that the change will lead to more efficient ways of producing quality education. Educational initiatives that attempt to create change often use a common process.

> In simple terms, someone or some group, for whatever reasons, initiates or promotes a certain program or direction of change. The direction of change, which may be more or less defined at the early stages, moves to a phase of attempted use (implementation), which can be more or

> less effective in that use may or may not be accomplished. Continuation is an extension of the implementation phase in that the new program is sustained beyond the first year or two (or whatever time frame is chosen). Outcome, depending on the objectives, can refer to several different types of results and can be thought of generally as the degree of school improvement in relation to given criteria. Results could include, for example, improved student learning and attitudes; new skills, attitudes, or satisfaction of the part of teachers and other school personnel; or improved problem-solving capacity of the school as an organization (Fullan, 1991, p. 48).

In reviewing the literature on school change, Fullan (1991) makes a number of key points. He states that the process of change is "detailed and snarled" with confounding variables. In other words the process is not linear, it feeds back on itself. The process is dependent on who initiates the change. The process is not easily demarcated in terms of time. This suggests that change should be viewed as a process not an event (Fullan & Park, 1981).

> "A lesson learned the hard way by those who put all their energies into developing an innovation or passing a piece of legislation without thinking through what would have to happen beyond that point" (Fullan, 1991, p. 49).

These common elements – details, knots, process – resonate in the project that is the subject of this paper - Common Knowledge: Pittsburgh[1] (CK:P). CK:P is a technology-based project in the Pittsburgh Public Schools. It was defined in its proposal to the National Science Foundation (NSF) as follows:

> This project will implement major changes in the teaching environment of the Pittsburgh Public Schools through the installation of an electronic data network that will ultimately be available to all students and teachers in the school district. The proposed network will be novel in its distributed architecture and distributed administrative structure. Teachers and students will use the network to access information and people outside of their classrooms. These new resources will be incorporated into the curriculum, and the network will be used as a tool for the development, implementation, evaluation and dissemination of new curriculum components (original proposal to NSF, 1992).

The CK:P project was implemented in two stages. The first (1993 to 1994) addressed the research question: **Is the Internet a viable tool for the K12 community?** During this stage, responsibility for project direction and fiscal management was through the University of Pittsburgh. The second stage (1995 through 1997), addressed a more difficult research question: **Can the lessons learned, in this**

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[1] National Science Foundation (RED – 9253452)

Internet based project, be institutionalized in the school district's organizational structure and strategic plan? Responsibility for management during this stage migrated to the school district. Because of the project's innovations and scope, both questions required the Pittsburgh Public Schools, its policy makers, middle managers, fiscal managers, curriculum specialists, staff and students, to enter into a dialogue about change in the organization's structure and focus with respect to instructional technology (i.e. school reform).

This paper is a case study of the ideology, strategies and process of the Common Knowledge: Pittsburgh project in its attempt at school reform in an urban school district. The paper reflects on the project's activities, looks at its efforts from the literature of school reform, and uses its experience to develop a conceptual framework for discussing such reform efforts. That conceptual framework is based on Chaos Theory (Gleick, 1987). The objectives of this paper are:

- to apply Chaos Theory, as developed in mathematics and science, to educational organizations, and
- to present a conceptual model for school reform consistent with this theory.

Chaos: Model or Metaphor?

Applying a relatively new theory of mathematical modeling – Chaos Theory – to human interactions begs the question: Is the application simply using the language of formal Chaos Theory as metaphor or is it applying an actual mathematic model to the discipline?

> It would be a legitimate debate whether NDS (non-linear dynamical system) is a true paradigm of social science or a metaphor run amuck. There is some truth to both sides of the debate. On the one hand, metaphorical thinking is a major component of creative thought. If an idea truly represents a new paradigm, it is likely that scientists will see applications of it everywhere; numerous phenomena will look different from what they had always looked like. On the other hand, metaphors can be notoriously misleading (Guastello, 1995, p. 60).

In order to address the metaphor/model issue, we are focusing on three key components – language, underlying assumptions and tools for application – of Chaos Theory.

This paper will use the language of Chaos Theory (see Appendix A), to describe the behaviors observed in CK:P. We believe that the behaviors exhibited, as a result of implementing the CK:P

project, are non-linear, dynamic, and similar at every level – individual, school, district – of magnification. We further suggest that, although much of the behavior appears to be random, chaotic and unpredictable, within the randomness there exist patterns – points of stable attraction. Whether behaviors gravitate towards these points of attraction is dependent upon initial conditions in the organization. By using the language of Chaos Theory to describe our reform efforts, we suggest, that at a minimum, it can be used as a metaphor.

Not only do we use the language of Chaos Theory, but we build on its assumptions and conceptual framework. The following is a list of key components of Chaos Theory that we apply to our observations and later to our model of school reform.

- When a catalyst is applied to a system, **noise** – local disorder, turbulence, and fluctuations – becomes apparent. This noise, although seemingly **random**, contains **patterns**, that when analyzed provide insight into the system's complexity. In human social systems, noise is seen as both a distraction and barrier to change.

- The noise generated when applying a catalyst to complex systems is dependent on **initial conditions** (Gleick, 1987, p. 23). In schools, these initial conditions pertain to the organization's inherent culture and the staffs' personal needs.

- The patterns found in the noise are similar at all levels of magnification. This **self-similarity** can be visualized by a fractal. Fractals are self generating landscapes which are identical at all levels of magnification. In educational organizations, the levels of magnification correspond to individuals, schools and districts.

- The system is **deterministic** – predictable given exact information about initial conditions. Unless one has perfect knowledge about the system being acted upon, minor differences in initial conditions can cause unpredictable behaviors.

We believe these assumptions map onto educational organizations. They provide a foundation for articulating the nature of change and its determinants. Using the assumptions that underlie Chaos Theory led us to believe that its application to educational reform is more than metaphor.

We are unable to state that Chaos Theory is the essential model for conceptualizing

organizational behavior. To do so would necessitate using the tools of Chaos Theory – mathematical modeling – to quantify the relationship between system variables, system parameters, and catalysts. At this point in time, we have identified a function that describes system behavior during school reform initiatives. We've also specified the variables that make up the function and are in the early stages of understanding the relationship between the catalyst – Lorenz's butterfly flapping its wings (Gleick, 1987), the Common Knowledge: Pittsburgh project – and the function's parameters, its loading on a particular variable. Presently, we are in the unenviable position of suggesting that our application of Chaos Theory to school reform is more than metaphor and less than mathematical model.

CASE STUDY – Common Knowledge: Pittsburgh[2]

Over a five year period from 1993 to 1997, Common Knowledge: Pittsburgh introduced wide area networks – the Internet – into all levels of the Pittsburgh Public Schools. CK:P was a collaboration among the Pittsburgh Public Schools (PPS), the University of Pittsburgh and the Pittsburgh Supercomputing Center (PSC). The PSC supplied technical support for the project, the University supplied project direction and evaluation and the school district supplied the educational staff to implement the project. It is important to note that the implementation staff consisted of all PPS teachers.

The school district administrator who acted as principal investigator on the grant and who shepherded the proposal through the political bureaucracy left the district as a result of a reorganization in 1993. This left the project without an administrative advocate just as it began. His departure also meant, that although the school district accepted the grant from NSF, the project was not part of any administrative niche or policy initiative. With project implementation left to teachers, CK:P ideology and strategies reflected a bottom-up perspective. This gave CK:P flexibility to act, with minimal constraints, at the individual and classroom levels in the school district.

Project implementation was guided by CK:P's underlying ideology developed by its founders – Mario Zinga (a PPS teacher) and Robert Carlitz (a University of Pittsburgh professor). The ideology can be characterized as constructivist in nature. It:

- placed value on ability at any level in the organization regardless of bureaucratic

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[2] Common Knowledge: Pittsburgh publishes all of its reports and activities on the World Wide Web at **<http://www.ckp.edu>**.

status,

- allowed the people who generated the idea to implement it,
- created a flat management structure rather than a hierarchial one,
- provided access to resources without gatekeepers,
- supplied tools that individuals could use to construct their own knowledge and become problem solvers,
- interacted with people electronically removing many occasions of bias,
- distributed expertise throughout the school district, and
- empowered and rewarded creativity on all levels of the organization.

This ideology was counter to that of traditional hierarchical systems:

> For the values that predominate most of all, that indeed must always predominate, are less the set of moral and social precepts which the critics have in mind than the institutional and organizational values on which the school itself is founded: respect for hierarchy, competitive individualization, a receptivity to being ranked and judged, and the division of the world of knowledge into discreet units and categories susceptible to mastery (Hodas, 1993; Dreeben, 1968).

A hierarchical approach would have required us to interact initially with curriculum developers and strategic planners and then legislate an implementation process. This would have placed the classroom teacher in the passive role of consumer, rather than developer of curriculum. By using a bottom-up implementation model, CK:P was at odds with the hierarchical paradigm of the school district. From the perspective of Chaos Theory, CK:P was a catalyst that clashed with the existing district culture and consequently contributed to unpredictable behaviors.

CK:P has had three iterations of implementation and each introduced into the organization a different combination of catalytic elements. The iterations are linear with respect to time. This case study will describe these iterations. The first iteration occurred prior to funding (1992) and during the first year of the project (1993). During this beginning phase, the change catalyst offered the Pittsburgh Public Schools was an idea with limited support. The idea was Internet access. Any PPS staff member could obtain an Internet account and access for free. The individual would have to provide a computer, modem, software and a phone line. There was limited support, first from the founders of CK:P and later, after the award from NSF, from the Common Knowledge: Pittsburgh staff. If needed, there was assistance with configuring the individual's computer for access. CK:P staff could also provide help at navigating the somewhat cryptic interface people were logging into. At this early stage, the support was limited due to a lack of maturity with the technology, lack of experience with its use in the classroom and too few personnel.

The effect of this initial catalyst appeared to be random behavior. For one reason or another, most people ignored the opportunity. They may not have been aware of the offer or they did not understand it as an opportunity. Also, they may have feared the technology and decided to take a wait-and-see approach, or possibly they were just too busy. However, within the random behavior resulting from the catalyst, we found two distinct patterns.

[Insert Figure 1 here]

There was a small group of teachers and curriculum specialists who immediately became enamored with the technology. They asked for accounts, went online, and fought through the technical morass in order to learn more about the Internet. They were invigorated by the idea of access and encouraged by the opportunity to receive support when needed. A closer look at this population showed that it had a history of getting involved with initiatives that involved technology, curriculum and pedagogy. These individuals were known among their peers as experimenters, first adopters and lone-wolves.

A second group immediately resisted the idea. These were school district personnel who were responsible for or had been involved in other technical initiatives – keyboarding, programming, management, information systems and computer maintenance. They felt that the ideas of Internet access and limited support were passing fads and not appropriate components for an urban school district. For example, why not use Compuserv or America Online for access? Wouldn't CD technology be more useful? How would network access be controlled? The support was also not welcomed, because it was provided by teachers, not traditional school support personnel. For this group of resistors, the ideology brought forward by CK:P was considered threatening. The act of providing an educational organization with an idea and limited support created behavioral patterns that seem predictable in retrospect. Certain people adopted the idea immediately because they believed it would benefit them, others resisted the idea because they felt threatened by it. But, most were neutral to the catalyst and therefore random in their behaviors.

The second iteration occurred during the second year of the project, 1994. According to the agreement with NSF, Common Knowledge: Pittsburgh was to provide seven new schools with local area networks (LAN) and wide area network (WAN) access to the Internet. There were three components to the catalyst in this iteration. It would seem that the most influential component was money. We would provide schools with approximately $75,000 worth of wiring, network equipment

and computers. Second, we would provide support, training and assistance both in person and online. And finally, we provided an option that allowed any school in the district to self-select into the process of becoming a CK:P site. In order for a school to become a CK:P site, it would have to respond to a district-wide Request for Proposals (RFP)[3]. Schools were given the opportunity to write up how they would use this access to benefit their students. Components of the proposal must include a curriculum project, a well-defined project team and an explanation of how the infrastructure addressed equity issues across the school district. The RFP would be reviewed and judged by a group of twenty-four teachers, students, parents, administrators and community members. The review committee, which did not include the CK:P educational staff, would choose the seven new schools. The RFP was consistent with CK:P's ideology and strategically addressed, what we perceived as, the needs of the educational staff in the school district. These needs pertained to cultural variables.

- **Language** The terms, idioms and acronyms that connote ideology and perception around technology in the classroom.
- **Peer group** The professional and social group that educators interact with. The group that brings pressure to bear on one's educational outlook.
- **Hierarchy** The bureaucratic structure and protocol of the educational organization.
- **Stereotypes** The biases educators have with regards to those that do technology.

They also pertained to personal variables.

- **Control** The desire to bring order and take ownership of one's immediate environment – department, office, classroom.
- **Ego** The confidence and self-esteem an educator brings to his/her job.
- **Flexibility** The willingness to try something new, to problem solve and to take on the role of learner.
- **Experience** An educator's background and practice at using technology both personally and in the classroom.

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[3] A complete description of the RFP process can be found on the World Wide Web at: **[http://info.pps.pgh.pa.us/publications/articles/rfp/cover.html]**.

These variables, cultural and personal, come from the literature on organizational change and personal growth, as well as from our experiences as educators implementing a technology initiative in the Pittsburgh Public Schools. We are not suggesting that these variables represent a comprehensive list, but they were evident in this particular case study. We believe these variables will generalize to other change efforts.

As in the first iteration, many schools chose not to participate. The prospect of receiving a $75,000 grant should have been appealing enough to insure almost universal participation. But it seemed that the RFP, through its competitive nature and its insistence on self-selection and self-definition, confounded the process. The initial conditions at many of the district's schools were such that they found the catalyst difficult to interact with. Those schools that did not participate exhibited random behaviors. However, there were patterns of both resistance and acceptance that were elaborations of those in the first iteration.

[Insert Figure 2 here]

Thirty-two schools and the teachers' union – Pittsburgh Federation of Teachers – wrote proposals. This represented a 37% participation rate. In this iteration the "first adopters" represented schools, not individuals. These schools responded to the idea, the support and money. They were reminiscent of the first adopters in the previous iteration. However, a closer look at this group suggested that there were deeper patterns that led to multiple points of attraction. The new patterns pertained to local dynamics – sensitivity to initial conditions – at the school. There appeared to be four distinct attractors with respect to those that wrote proposals. These included:

- creative leaders with a vision who authored the proposal and brought staff along,
- individual teachers who wrote the proposal and brought other faculty along,
- collaborations where teams of teachers worked together to author the proposal, and
- lone-wolves who agreed to work together, temporarily, in order to write the proposal.

Each of these groups represented points of attraction, that stood out among the chaos generated by the catalyst. And each, due to the nature of its local conditions, created different proposals with different results.

Like before, there was also a group of resistors. These resistors focused on and disagreed with

the concept of the RFP. They suggested that competition had no place in public education. They were upset that resources were not being distributed in an *equitable* manner. Competition was perceived as diametrically opposed to the idea of equity. They also felt that a competition was counter to school district policy. And they questioned the integrity of the review procedure, believing it impossible to create a selection process free of political pressures. This group of resistors included teachers, administrators, and elected board members.

The final iteration occurred in 1996. By this point we had additional funding from NSF to institutionalize the project in the school district. The project was four years old and the RFP process had occurred twice, in 1994 for the entire school district, and again in 1995 for the district middle schools. In this iteration, there were multiple indicators that the project had reached maturity, making significant inroads into the culture of the school district.

- Over half of school district staff had email accounts.
- Twenty schools had LAN/WAN access to the Internet through CK:P.
- Five non-CK:P schools used the CK:P model to provide LAN/WAN access at their sites.
- Another fifty-four PPS schools had Internet access from a single computer over a dial-up modem.
- A plan for migrating technical support from the project to the PPS was agreed to by PPS management.

In accepting the second phase of NSF funding, the Pittsburgh Public Schools took responsibility for project management and agreed to institutionalize the program across the school district. However, no one was quite sure what that meant. We knew it meant that the district would provide the technical support for maintaining access after NSF funding was gone. We hoped that the PPS would also maintain educational support. However, we had no idea how this promise to institutionalize would play out.

In the third iteration new components were added to the catalyst, but not by CK:P. The idea, support and money were identical to the previous iteration. The new components were a result of project duration and the prospect of long-term support from the Pittsburgh Public Schools. After four years, the project had made an impact on teachers and schools throughout the district. There were Internet access points at seventy-nine of the ninety schools in the district. In addition there was, from a

PPS administrative perspective, a migration plan in place that described how the school district would support the activity after completion of the NSF grant.

We would suggest that the additional components in the catalyst resulted from a cultural perspective – the project had reached acceptance within the school district. Schools that were using Internet technologies in powerful ways were receiving praise from educational experts, the NSF, and members of the community. Schools began to feel accountable for obtaining Internet access either through CK:P or by some other means. Finally, there was a sense of power and modernity associated with having such access. This power was attributed to the underlying goals and ideology of CK:P – access to resources, power regardless of bureaucratic status, and distributed expertise. Time, success with technology and the experiences of CK:P in the school district were now having an effect on district behaviors.

[Insert Figure 3 here]

The RFP in the last year of the project was open to all non-CK:P schools in the district. The response was overwhelming. Forty-one out of sixty-nine eligible schools wrote proposals for nine available grants. The patterning for the adopters was similar to that in the second iteration. There was a significant change with respect to the resistor population. There was a bifurcation into blind-resistors and pseudo-resistors. Schools, administrators and individuals who were either oblivious or against the CK:P program, began to exhibit behaviors that indicated they were moving towards its ideology. For example:

- school district administrators responsible for technology services began to offer Internet connectivity;
- curriculum support staff, who refused to acknowledge the benefit of this technology, began using it for both internal communication and publishing; and
- schools that had previously fought the use of technology, now felt the need to write a proposal.

In our discussions with these groups – administrators, support staff, technology-poor schools – they still had the demeanor of resistance, but their behaviors indicated acceptance of the change model. These resistors were effected by the components of the catalyst that pertained to power, accountability

and praise. Money was scarce, the district still had no technology plan, and the only schools getting technology were those willing to fight for it. The RFP was seen as a vehicle to get money and technology. Change in the resistor group indicated that the catalyst has had an influential effect on the organization. The initial conditions within the school district had changed.

Fullan (1991) talks about change being a process over time. He suggests that successful change efforts are comprehensive, have adequate resources, and are provided with substantial time for implementation. The National Science Foundation provided CK:P and the Pittsburgh Public Schools with five years of funding. This allowed us to reflect after each iteration and create a catalyst that considered the existing conditions in the district. CK:P, using an ideology based in learning and organizational theory and instantiated through a voluntary process of implementation, had a significant impact on the school district. We have defined school reform as change that becomes inculturated as a new set of initial conditions.

Developing a Conceptual Framework

The educational change literature (Fullan, 1991) differentiates between change in the individual and change in school organizations. It is common to invoke psychological frameworks that apply theories of cognition, learning, motivation, attitudes and beliefs when considering individual change. It is common to use organizational frameworks that apply theories of sociology, group dynamics and systems analysis when discussing change at an organizational level. We believe that to move from change to reform, a holistic approach must be taken that considers the system and all of its components. In generating a conceptual model of school reform we'll apply Chaos Theory to educational organizations considering both local and global complexities.

The Function

We describe the process of change as a recursive function. Through this function we attempt to model the patterns generated in the seemingly random behaviors that we observed. The function ideally would allow us to trace the patterns back to initial conditions present in the individuals and the environment. The function contains cultural variables in the organization, personal variables internal to the individual, and parameters which determine the influence of each variable. We believe that the

sum total of the effect of the variables corresponds to an individual's needs. When a catalyst acts upon the system, it influences the weight of each variable through its associated parameter. Once the value of the parameter is determined and the initial values of the variables are established, the recursion of the function can begin. After the function is evaluated, a new set of values exist for each variable. New values for any of the variables suggest that the catalyst has effected the organization and/or the individual. If the new values are different from the initial values, then some type of change has occurred. As long as the catalyst remains in the system in some active form, the function will continue to recurse.

[Insert Figure 4 here]

The Variables

Our experience suggests there are both cultural and personal variables that effect the participants of the organization one is trying to change. Cultural variables in a school district pertain to the rules or mores the organization and its members create and use. We used the following cultural variables as starting points in our study of the PPS:

- the **language** used within the organization to both control and empower its employees;
- the pressure from one's **peer group** to not deviate from acceptable behaviors;
- the organization's **hierarchy** and its desire to maintain clear lines of authority; and
- the **stereotypes** educators use and their effect on organizational behavior.

These variables provide the context within which change may or may not occur.

Internal variables are specific to each person in the organization. The following internal variables pertain to the needs of the individual:

- the need to **control** one's environment – classroom, school, district:
- the need to limit threats to one's **ego** and self esteem;
- one's **flexibility** – willingness to experiment and take on the role of learner; and
- one's previous **experience** with change, innovation, and experimentation.

Each individual in the organization will have different initial values for each variable. The initial values of both the cultural and personal variables represent the initial conditions in the organization. We are not suggesting that this is a comprehensive list, rather they were the variables we observed in our case study. They reflect our experience in the field of education, and are referenced in the literature (Fullan, 1991).

The Catalysts

Systems, in the real world, do not evolve in a vacuum, rather they are constantly interrupted by outside agents. The system in this case study – an educational organization – is also subject to outside agents. The agents – financial incentive, political pressure, legislative dictate, strategic planning, change in leadership – can be chosen with a specific intent in mind and/or a thorough understanding of the organization's initial conditions. Agents such as environmental disasters, scandals, death, power struggles, unexpected financial swings tend to be oblivious to the initial conditions and accidental in their intent. Agents influence the system in varied ways. A given agent of change – a catalyst – interacts with aspects of the organization and may influence behavior. Whether or not the catalyst changes behaviors is based on its alignment with the organization's cultural variables and the individuals' personal needs within the organization.

The catalyst in the CK:P project were different in each of the three iterations. In the first iteration the catalyst of idea and limited support was chosen with a specific intent in mind – increasing staff knowledge and willingness to experiment. The second iteration was an example of attempting to choose a catalyst which would align closely with the cultural and personal variables and therefore maximize change. The intent was to force the idea of instructional, networking technology into the school district. The catalyst contained money (an obvious incentive) and a synergetic process (the RFP) which aligned, in both positive and negative ways, with the variables. The third iteration, while using the same components of idea, support, and money, had the secondary/accidental set of components – accountability, praise, and power. The accidental components forced the idea deeper into the organization while teasing out a new stable attractor – pseudo-resistor.

The Parameters

A parameter is a measure of how the catalyst aligns with each variable. The initial values of

the parameters are generated through the interaction between the catalyst and the cultural and personal variables. Let's use the first iteration of CK:P to demonstrate how parameters might be determined. The introduction of the Internet into the school district occurred with an initial offering of accounts and support and a grant award from the National Science Foundation. The catalyst was an idea and limited support. At the moment the catalyst was applied, everyone in the school district had some initial value for each variable. Depending on one's role in the organization, one's personal needs, and the particular catalyst being introduced, the loading on each variable was different. This loading is done by generating the value for each parameter **a** through **h**, (see Figure 4). The value is generated by the alignment between the catalyst and the variables.

Variables - Catalyst 1	language C_1	peers C_2	hierarchy C_3	stereotype C_4	control P_1	ego P_2	flexibility P_3	experience P_4
idea	a_1	b_1	c_1	d_1	e_1	f_1	g_1	h_1
support (limited)	a_2	b_2	c2	d2	e2	f_2	g_2	h_2
Total	$a_1 + a_2 = a$	$b_1 + b_2 = b$	$c_1 + c_2 = c$	$d_1 + d_2 = d$	$e_1 + e_2 = e$	$f_1 + f_2 = f$	$g_1 + g_2 = g$	$h_1 + h_2 = h$

The starting parameter value will be different for each individual or entity that the catalyst comes into contact with. This is due to the individual differences in initial values of the variables. For example, differences would exist between:

- a teacher who never used technology,
- a superintendent of schools who is afraid of technology,
- a physics teacher who was nominated for Science Teacher of the Year,
- a curriculum supervisor in Mathematics who just found out that his/her position and department are being eliminated, and
- the director of computer services responsible for the purchase and maintenance of school district computer systems.

Although the authors of this paper have yet to create a method to determine how the initial values of the parameters are generated, we can conjecture that their values are different for each of the

individuals above. For arguments sake, we will choose numeric values for each parameter that range from –10 to 10. Values are positive when the interaction due to the catalyst makes the variable more influential, values are negative when the interaction due to the catalyst makes the variable less influential. The value equals zero when the interaction due to the catalyst makes the variable inconsequential.

The following is a sample interaction for the teacher who has never used technology. Let's assume the teacher is female, fifty-five years old, two years from retirement, works in a school with little or no technology and has no friends who use technology. However, her daughter is in college and keeps asking her to get email so they can correspond.

Variables → Catalyst ↓	language C_1	peers C_2	hierarchy C_3	stereotype C_4	control P_1	ego P_2	flexibility P_3	experience P_4
idea	–5	6	0	–5	–10	–5	–3	2
support (limited)	0	10	0	3	2	–2	4	3
Parameter Total Value	–5	16	0	–2	–8	–7	1	5

These initial values are strictly conjecture. They beg the question: "What heuristics might exist that would allow one to make such judgements?" We suggest these values are based on our experiences as educators. For example, the teacher says, "I don't understand all of these new words. Look, I hate technology. I'm afraid of it. I'm too old for all this. All I want to do is retire before I'm forced to learn it. No one can make me to do this."

When confronted with a new idea pertaining to technology and Internet use, this teacher assumes the negative stereotype about technology, fears loss of control, feels a threat to her ego, and is intimidated by the jargon, consequently she loads negatively on these variables. Yet her experience with those offering the support is positive. From a professional perspective, she is willing to try a new idea if she is provided with the necessary support, and she would desperately like to communicate with her daughter so she loads positively in the areas of peers – daughter, flexibility and experience. The catalyst provides no weight whatsoever with respect to the variable on hierarchy since she has little concern that she will be told by her superiors to learn this technology.

Starting the Function

The implementation of this change function is a recursive process continuing until the function reaches some limiting behavior. The function begins when the catalyst is introduced into the organization. Over time, the value of the function either goes off to infinity or converges to a single data point. Anyone in the organization with identical initial values will end up at the same point. In the first iteration of CK:P, we found a cluster of data points at two stable attractors – resistors and first adopters (see Figure 1). This bifurcation showed a branching based upon a specific set of initial conditions – groups of people with similar, if not identical, characteristics. The others in the system were not similar enough to be within a basin of attraction.

In mathematical models of chaos, there are a number of end-behaviors. Recursing a non-linear difference function [$x_{new} = rx(1-x)$] can result in limiting behavior that approaches infinity, that approaches zero, that approaches a constant or multiple constants, or remains random – chaotic. End behavior is determined by the initial values of **r** (the parameter) and **x** (the variable). We define net change as being the difference in variable values as a result of a catalyst.

We would suggest two possible end-behaviors to recursing our change function. The first would be reaching equilibrium – stability. In this case, each recursion provides smaller and smaller differences in the variable values. The limit of the values of the variables is significantly different than the initial-values of the variables.

- The function reaches a limit that is a constant – stable attractor. This value is different from the initial value of the variables.
- The function exhibits end-behaviors that cycle between multiple constants, each being a constant – stable attractor.

At the stable attractor, there is no further change due to the catalyst. Equilibrium is when the reform effort, via the catalyst, has become part of the culture and part of the individuals in the organization. Since it is now part of the culture and experience of the people in the organization, it becomes part of the determinant of the initial conditions for the next reform effort.

The second conclusion is when the reform effort becomes extinct. In the mathematical model, this occurs when the function becomes zero, approaches infinity or produces random, chaotic values.

- The initial values of the variables are identical before and after the catalyst. This corresponds to a limit of zero. No change occurred.
- The values of the variables go to infinity. In human-based systems, this occurs when people or organizations go off on what appear to be uncontrolled tangents. Organizations such as school districts are controlled environments that do not allow radical behaviors. If the function behavior changes too rapidly, as it does when it approaches infinity, the activity is halted.
- The values of the variables appear to be random. This corresponds to behaviors that have little focus, direction or accountability. School districts do not tolerate this type of behavior.

These are examples where reform efforts die without success – become extinct. The programs implemented are not sustained or integrated. They are forgotten, except in the faculty room.

Final Thoughts

The introduction of Common Knowledge: Pittsburgh into the Pittsburgh Public Schools engaged traditional attitudes and behaviors, both negative and positive, found in any school district. Pioneer teachers and schools were enamored with the technology; building administrators were accepting yet cautious; and school district leaders were publicly supportive and privately reserved. We also discovered behaviors of refusal (Hodas, 1993). These hostile attitudes and behaviors appeared as background noise – bureaucratic disorder and cultural dissonance. Initially, we assumed that the noise was a manifestation of the traditional barriers to change and that it would eventually dissipate. However, as we began to attend to the noise – analyze, synthesize, model and predict – we noticed patterns in the dissonance. Attending to the noise allowed us to succeed at implementing an agent of change into an urban school organization and forced us to the broader concept of school reform.

Can we really describe our efforts in the Common Knowledge: Pittsburgh project as school reform? We suggest that there are at least 4 elements that have to be present for reform to occur. First, individual or cultural change must occur that is irreversible. Second, for a change effort to become reform it must achieve a critical mass – a majority has to internalize the change. The three thousand staff members who actively use the Internet and the thirty-four schools who have LAN/MAN/WAN

access have permanently changed their beliefs and behaviors pertaining to instructional technologies[4]. Third, institutional shifts must occur that put into place the elements – budgets, staff, curriculum and infrastructure – to support and sustain the change. At each CK:P school, one can find these elements. Fourth, the change must conform to some standard agreed upon by the local and professional community. This standardization attempts to address some gap or weakness in the system that is undermining the success of the organization. The intervention attempted via the CK:P project is consistent with national and professional standards (NCTM, 1989; NRC, 1995; NRC, 1989; NCEE, 1983). We believe that CK:P fulfills these elements and qualifies as reform.

So what is the benefit of applying Chaos Theory to school reform? Chaos Theory is a holistic process for analyzing complex systems. Traditional research designs controlled environments by limiting local variables. By contrast, Chaos Theory through mathematical modeling, looks at systems globally while addressing local variables. It attempts to replicate a system's complexity by considering both the existing turbulence and that generated when introducing an agent of change. We believe that Chaos Theory places other relevant ideologies and strategies – psychological, educational, organizational – into a dynamic context providing a common language through which these theories can interact.

> Those studying chaotic dynamics discovered that the disorderly behavior of simple systems acted as a *creative* process. It generated complexity: richly organized patterns, sometimes stable, sometimes unstable, sometimes finite, and sometimes infinite, but always with a fascination of living things (Gleick, 1988, p. 43).

Chaos Theory has provided us with a unifying concept for analyzing our efforts.

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[4] Further information of school activities in the Common Knowledge project can be found at: [(http://info.pps.pgh.pa.us/curriculum/curriculum.html)].

Appendix A
Glossary of Terms

Attractor: The status that a dynamic system eventually settles down to. An attractor is a set of values in the phase space to which a system migrates over time, or iterations. An attractor can be a single fixed point or a collection of points regularly visited (Clayton, 1996). Synonyms – equilibrium and points of stability.

Basin of attraction: A region in phase space associated with a given attractor. The basin of attraction is the set of all, initial points that go to the attractor (Clayton, 1996).

Bifurcation: A qualitative change in the behavior – attractor – of a dynamic system associated with a change in control parameter (Clayton, 1996).

Catalyst: An agent of change.

Dynamic Systems: A set of equations specifying how certain variables change over time. The equations specify how to determine – compute – the new values as a function of their current values and control parameters (Clayton, 1996).

Fractals: An irregular shape with self-similarity. It has infinite detail, and cannot be differentiated (Clayton, 1996).

LAN: Local Area Network. The wiring together of computers within a single building. LANs allow users to share files and resources within a physical setting.

MAN: Metropolitan Area Network. The wiring together of schools within the school district – Pittsburgh Public Schools.

Nonlinear Dynamic Systems: A function that describes behavior over time which is iterative and non-linear.

Recursion: Defining a function by the repeated application of some process.

Self- organization: Systems that are capable of capturing information that they themselves generate, and then use the new information as input to the system. This is a key element of applying Chaos Theory to human endeavors.

Self-similarity: An infinite nesting of structure on all scales. Strict self-similarity refers to a characteristic of a form exhibited when a substructure resembles a superstructure in the same form (Clayton, 1996).

WAN: Wide Area Network. A network of networks that connect computers around the world. The Internet is an example of a wide area network.

WWW: The World Wide Web. An Internet multimedia interface that allows users to publish resources, access data and navigate the network through links.

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Bifurcation Diagram
1st Iteration

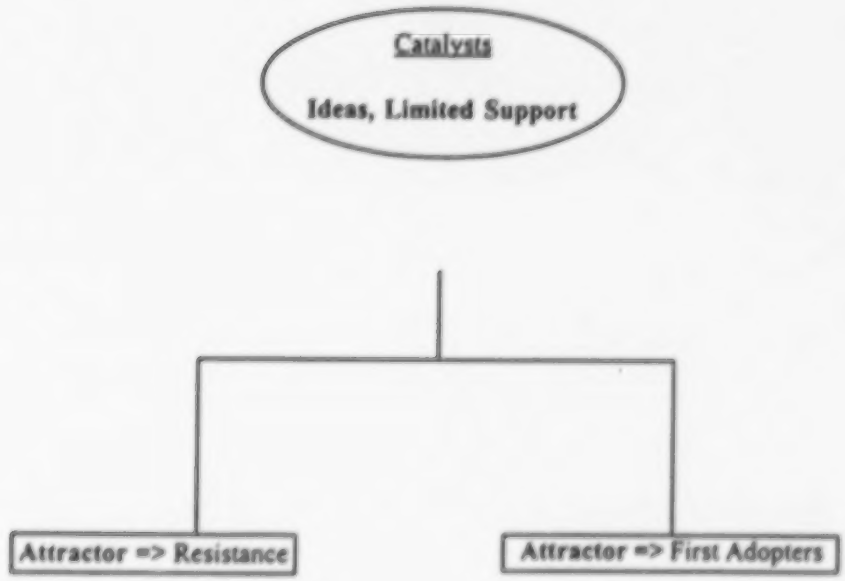

Figure 1

Bifurcation Diagram
2nd Iteration

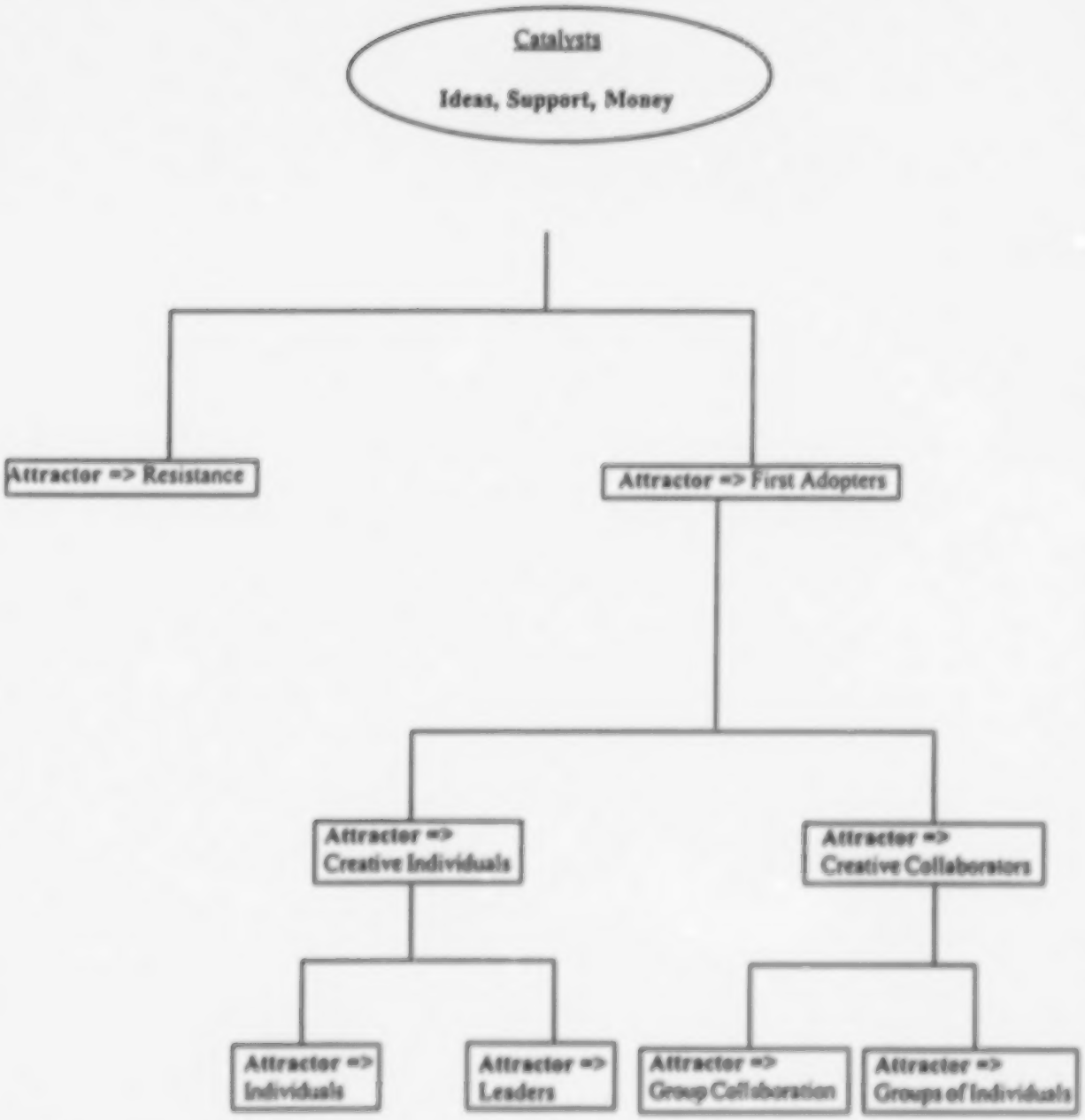

Figure 2

Bifurcation Diagram
3rd Iteration

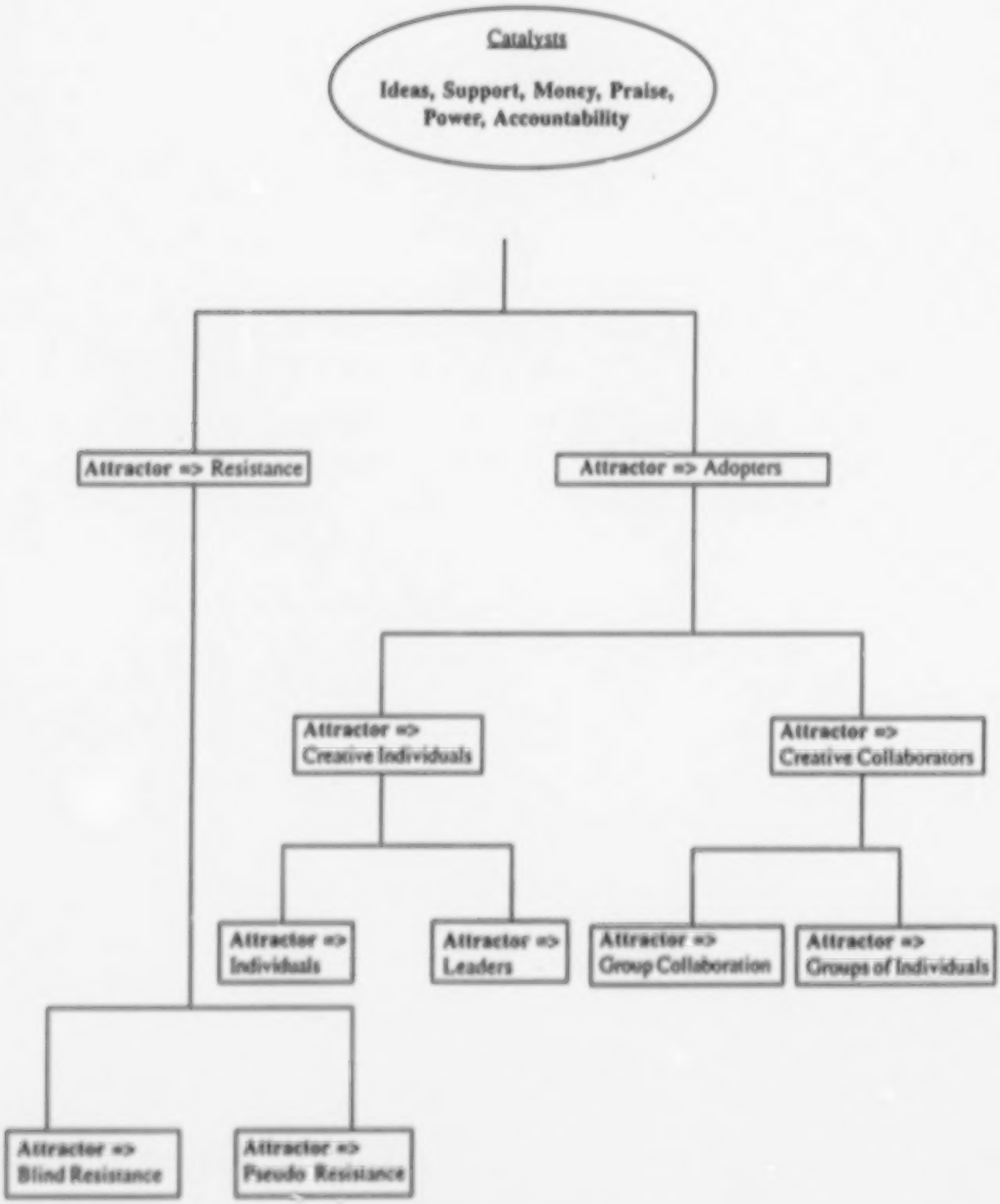

Figure 3

$$Needs_n = aC_1 + bC_2 + cC_3 + dC_4 + eP_1 + fP_2 + gP_3 + hP_4$$

Cultural Variables
- language (C_1)
- peer group (C_2)
- hierarchy (C_3)
- stereotypes (C_4)

Personal Variables
- control/ownership (P_1)
- ego (P_2)
- age/flexibility (P_3)
- experience (P_4)

Parameters

a – loading based on interaction between the catalysts and language used in the system.

b – loading based on interaction between the catalysts and values of one's peer group.

c – loading based on interaction between the catalysts and organizational protocol/hierarchy.

d – loading based on interaction between the catalysts and age/race/gender stereotypes.

e – loading based on interaction between the catalysts and an individual's need for control.

f – loading based on interaction between the catalysts and an individual's self-esteem.

g – loading based on interaction between the catalysts and an individual's ability to change.

h – loading based on interaction between the catalysts and an individual's history with change.

$$Needs_n = Needs_{n-1} \times Catalysts$$

$$Change = Needs_n - Needs_o$$

Figure 4